US-PAT-NO: 6376862

DOCUMENT-IDENTIFIER: US 6376862 B1

TITLE: Semiconductor device and its manufacturing method

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A crystalline silicon film is obtained by forming an amorphous silicon film through plasma CVD or low-pressure thermal CVD, and then **crystallizing** it through a heat treatment or **irradiation** with laser light.

On the other hand, although the method using the laser light **irradiation** can provide superior crystallinity partially, it is difficult for even such a technique to provide good annealing effects over a wide area. In particular, **irradiation** with laser light under such conditions as to provide a high degree of crystallinity tends to be unstable.

A technique described in Japanese Unexamined Patent Publication No. Hei. 6-232059 is known as a method for solving the above problems. In this technique, a **metal** element (for instance, nickel) for accelerating crystallization of silicon is introducing an amorphous silicon film, thereby providing a crystalline silicon film by a heat treatment of a lower temperature than in conventional techniques.

However, this technique has a problem that delicate control is needed for the introduction amount of a **metal** element because it remains in a resulting film. Accordingly, it has been found that this technique is problematic in reproducibility and(electrical stability of a device produced.

In addition, there is a problem that the characteristics of a semiconductor device produced considerably varies with time, which is an influence of a residual **metal** element. The residual **metal** element also causes a problem that the off-current of a thin-film transistor fabricated by using the above-mentioned film is large.

That is, although the **metal** element for accelerating crystallization of silicon is very useful to form a crystalline silicon film, it is associated with negative factors that cause various problems after formation of a crystalline silicon film.

An object of the present invention is to provide a technique for reducing the concentration of a **metal** element for accelerating crystallization of silicon in a crystalline silicon film formed by utilizing the **metal** element. Another object of the invention is to provide a thin film semiconductor device having superior electrical characteristics by utilizing the film formed in the present invention.

According to one aspect of the invention, there is provided a manufacturing method of a semiconductor device, comprising the step of forming a crystalline silicon film on a substrate by using a **metal** element for accelerating crystallization of silicon, wherein during the step, a maximum process temperature (the highest temperature during the process) is higher than 650.degree. C. and lower than 1,000.degree. C., and a process time not shorter than one hour; the substrate contains OH group at 50-2,000 ppm and chlorine at 10-1,000 ppm; and the substrate has a strain point of 650.degree.-1,000.degree. C.

According to another aspect of the invention,there is provided a manufacturing method of a semiconductor device, comprising the step of forming a crystalline silicon film on a substrate by using a **metal** element for accelerating crystallization of silicon, wherein during the step, a maximum process temperature be higher than 700.degree. C. and lower than 980.degree. C. and a process time be not shorter than 30 minutes.

According to another aspect of the invention, there is provided a manufacturing method of a semiconductor device, comprising the steps of forming a crystalline silicon film on a substrate by using a **metal** element for accelerating crystallization of silicon; and removing the **metal** element from the crystalline silicon film by forming a thermal oxidation film containing a halogen element, wherein each of the two steps has a maximum process temperature that is higher than 650.degree. C. and lower than 1,000.degree. C., and a process time not shorter than one hour; the substrate contains OH group at 50-2,000 ppm and chlorine at 10-1,000 ppm; and the substrate has a strain point of 650.degree.-1,000.degree. C.

According to another aspect of the invention, there is provided a semiconductor device comprising a silicon thin film formed on a substrate, wherein the substrate contains OH group at 50-2,000 ppm and chlorine at 10-1,000 ppm; the substrate has a strain point of 650.degree.-1,000.degree. C.; the silicon thin film contains a **metal** element that accelerates crystallization of silicon at a concentration of 1.times.10.sup.16 to 5.times.10.sup.19 cm.sup.-3, the **metal** element existing at a high concentration in the vicinity of a interface of the silicon thin film.

Where a **metal** element for accelerating crystallization of silicon is used, the concentration of the residual **metal** element in a resulting crystalline silicon film is within the above range. If a crystalline silicon film contains a **metal** element at a higher concentration than the above range, it is too much influenced by the **metal** element to exhibit semiconductor characteristics. Further, the reliability of a semiconductor device is extremely lowered.

According to still another aspect of the invention, there is provided a semiconductor device comprising a silicon thin film formed on a substrate, wherein the substrate contains OH group at 50-2,000 ppm and chlorine at 10-1,000 ppm; the substrate has a strain point of 650.degree.-1,000.degree. C.; the silicon thin film contains a **metal** element that accelerates

crystallization of silicon at 1.times.10.sup.16 to 5.times.10.sup.19 cm.sup.-3, and a halogen element at not less than 1.times.10.sup.16 cm.sup.-3.

According to a further aspect of the invention, there is provided a semiconductor device comprising a silicon thin film formed on a substrate, wherein the substrate has a strain point of 650.degree.-1,000.degree. C.; and the silicon thin film contains a **metal** element that accelerates crystallization of silicon at 1.times.10.sup.16 to 5.times.10.sup.19 cm.sup.-3, and a halogen element at not less than 1.times.10.sup.16 cm.sup.-3.

In the invention, the **metal** element may be one or a plurality of elements selected from Fe, Co, Ni, Ru, Rh, Pd, Os, Ir, Pt, Cu, and Au.

Next, a crystalline silicon film is obtained by **crystallizing the amorphous silicon** film by action of a **metal** element, as typified by nickel, for accelerating crystallization of silicon. This is done by a heat treatment with the aid of laser light **irradiation**.

The crystalline silicon film obtained by the above heat treatment contains the **metal** element at a considerable concentration.

Then, a heat treatment is performed in an oxidizing atmosphere containing HCl, to form a thermal oxidation film on the surface of the crystalline silicon film. In this heat treatment, the **metal** element moves to the thermal oxidation film to be contained therein at a high concentration. As a result, the concentration of the **metal** element in the crystal silicon film decreases.

The temperature of the heat treatment is set within the range of 650.degree.-1,000.degree. C. If the temperature is lower than the above range, a thermal oxidation is not formed properly, so that the **metal** element is not removed efficiently from the crystalline silicon film.

By setting the chlorine concentration in the above range, the substrate side

is given a **metal** element gettering function.

It is effective to add a very small amount of halogen element as typified by chlorine to the undercoat film 102. The halogen element can getter a **metal** element for accelerating crystallization of silicon existing in a semiconductor layer in a later step.

It is desired that the amorphous silicon film 103 contain oxygen at 5.times.10.sup.17 to 2.times.10.sup.19 cm.sup.-3, because oxygen plays an important role in a later step for gettering a **metal** element (for accelerating crystallization of silicon).

The method of using a solution is advantageous because it is simple and convenient and the **metal** element concentration can easily be adjusted.

The above heat treatment is intended to remove nickel (or some other **metal** element for accelerating crystallization of silicon), which has intentionally been introduced for crystallization at the initial stage, from the crystalline silicon film 105. It is preferred that this heat treatment for thermal oxidation is performed at a higher temperature than the heat treatment performed for the crystallization in order to enhance the nickel gettering effect.

If the heating temperature is set high, the time for forming the desired thermal oxidation film 106 is shortened. Because of **he** shortened processing time, that the effect of gettering nickel from the silicon film 105 into the thermal oxidation film 106 becomes insufficient. To solve this problem, it is effective to reduce the oxygen density in the atmosphere, thereby to lower the rate of forming the thermal oxidation film 106.

As a result of this step, the nickel concentration can be reduced to 1/10 of the initial value in the best case. This means that the nickel concentration can be reduced to 1/10 of the case where no gettering by a halogen element is

effected. This similarly applies to cases of using other **metal** elements.

This embodiment is directed to a case where after a crystalline silicon film is obtained by the heat treatment in the first embodiment (see FIG. 1C), laser light **irradiation** is performed to improve its crystallinity.

When the temperature of the heat treatment for crystallization is low or the processing time is short, that is, when the heating temperature or the heating time is restricted for a certain reason relating to the manufacturing process, a necessary level of crystallinity may not be attained. In such a case, a necessary, high level of crystallinity can be attained by further performing annealing by laser light **irradiation**.

In this laser light **irradiation** after the heat treatment, the allowable ranges of the laser **irradiation** conditions are wider than in the case of **crystallizing an amorphous silicon** film only by laser light **irradiation**. Further, the reproducibility of the laser light **irradiation** step is high.

The laser light **irradiation** may be performed after the step of FIG. 1C. In this embodiment, it is important that the thickness of the amorphous silicon film 103 as the starting film be 200-2,000 .ANG.. This is because the annealing effects by the laser light **irradiation** are more remarkable when the amorphous silicon film 103 is thinner.

This embodiment is directed to a case where Cu is used as the **metal** element for accelerating crystallization of silicon in the first embodiment. In this case, Cu may be introduced by using a cupric acetate (Cu(CH.sub.3 COO).sub.2) solution or a cupric chloride (CuCl.sub.2.2H.sub.2 O) solution.

This embodiment is directed to a case where crystal growth mode is different from that described in the first embodiment. More specifically, in this embodiment, crystal growth parallel with a substrate, called lateral growth, is effected by utilizing a **metal** element for accelerating crystallization of

silicon.

As shown in FIG. 2E, the pattern 210 which consists of only a lateral growth region has a lower residual nickel concentration than even a crystalline silicon film obtained according to the first embodiment. That is, because the concentration of a **metal** element in a lateral growth region is low. Specifically, the nickel concentration in the pattern 210 consisting of a lateral growth region can easily be made less than the order of 10.sup.17 cm.sup.-3.

It is effective to cause the silicon oxide film 304 to contain a halogen element. That is, by fixing nickel by the action of the halogen element, it can be prevented that the function, as an insulating film, of the gate insulating film is lowered being influenced by nickel (or some other **metal** element for accelerating crystallization of silicon) existing the active layer 303.

If trap states exist on the side faces of the active layers 503 and 504 due to the existence of a **metal** element, the off-current characteristic is deteriorated. Therefore, it is effective to decrease the density of such trap states by the above treatment.

Then, a 4,000-.ANG.-thick aluminum film (not shown) to later constitute a gate electrode is formed. Instead of aluminum, some other **metal** capable of being anodized, such as tantalum, may be used.

First, a crystalline silicon film is formed by utilizing the action of nickel as described in the first embodiment. The crystallinity is improved by **irradiating** the crystalline silicon film with excimer laser light (for instance, laser light emitted from a KrF excimer laser). During this step, a heat treatment is also performed at not lower than 450.degree. C. and the laser light **irradiation** conditions are optimized, whereby a single crystal region or a region that can substantially be regarded as a single crystal is formed.

In this embodiment, nickel is directly applied after formation of an undercoat film to establish a state that nickel (i.e., a **metal** element) is held adjacent to the surface of the undercoat film. Nickel may be applied by using a solution or by some other method such as sputtering, CVD, or an absorption method.

Then, nickel is introduced to the amorphous silicon film by a method using a nickel acetate salt solution as described in the first embodiment. A crystalline silicon film is obtained by **crystallizing the amorphous silicon** film by performing a heat treatment at 650.degree. C. for 4 hours.

As described above, the invention can reduce the concentration of a **metal** element in a crystalline silicon film obtained by utilizing the **metal** element. As a result, a thin-film semiconductor device having superior electrical characteristics can be obtained.

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TITLE: Method for fabricating semiconductor device with high quality crystalline silicon film

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An amorphous silicon film is deposited on a quartz substrate, and a **metal** of Ni is introduced into the amorphous silicon film so that the amorphous silicon film is crystallized. Phosphorus is ion-implanted with an oxide pattern used as a mask. A heating process is performed in a nitrogen atmosphere, by which Ni is gettered. A heating process is performed in an O.sub.2 atmosphere, by which Ni is gettered into the oxide. Like this, by performing the first gettering in a non-oxidative atmosphere, the Ni concentration can be reduced to such a level that oxidation does not cause any increase of irregularities or occurrence of pinholes. Thus, in a second gettering, enough oxidation can be effected without minding any increase of irregularities and occurrence of pinholes, so that the Ni concentration can be reduced to an extremely low level. Also, a high-quality crystalline silicon film free from surface irregularities and pinholes can be obtained.

Also, by enhancing the TFT performance up to an equivalency to MOS (**Metal** Oxide Semiconductor) transistors of single crystal silicon, it becomes possible to achieve newly functioned devices and so-called 3D ICs, which take advantage of characteristics as SOI (Silicon On Insulator). Like this, for enhancement in TFT performance, it is indispensable to achieve higher qualities of crystalline silicon films constituting the active region, i.e., scale-up of crystal grains, improvement in orientation characteristics, reduction in defect

density and reduction in impurities.

After a metallic element serving for acceleration of crystallization is introduced into an amorphous silicon film so that the amorphous silicon film is crystallized, a mask is formed selectively on the amorphous silicon film. Then, one kind or a plurality of kinds of elements among nitrogen, phosphorus, arsenic, antimony and bismuth are added, and the **metal** in regions where the element or elements are not added is gettered into the region where the element or elements are added. More specifically, this is carried out as follows (see FIGS. 7A to 7F):

(2) Further, Ni acetate 13 is formed by spin-coating a Ni acetate solution having a Ni concentration of 100 ppm, and a **metal** of Ni is introduced into the surface of the amorphous silicon film 12.

Unfortunately, in the crystalline silicon film that has been crystallized by heating process performed after the implementation of a **metal** serving for acceleration of crystallization into amorphous silicon film, the **metal** serving for acceleration of crystallization is distributed not uniformly but unevenly. In particular, at grain boundaries at which a plurality of crystal grains contact one another, high-concentration metals are present in a state of compound with silicon. In Japanese Patent Laid-Open Publication HEI 7-192998, the crystalline silicon film is oxidized in order to reduce the remaining metals, in which case oxidation considerably proceeds at grain boundaries where metals are present at high concentrations, and after the oxidation, irregularities of the crystalline silicon film surface are considerably increased. There are some cases where pinholes may be formed particularly at grain boundaries where a plurality of crystal grains contact one another. Avoiding these possibilities makes it impossible to attain enough oxidation for the purpose of gettering, as a problem. Also, irregularities of the crystalline silicon film surface adversely affect the TFT characteristics and cause the carrier scattering to be so large that successful characteristics could not be obtained, as another problem.

(c) Conducting a 12 hour heating process at a temperature of 600.degree. C. in a nitrogen atmosphere, thereby **crystallizing the amorphous silicon** film to obtain a crystalline silicon film;

(c) Conducting a 12 hour heating process at a temperature of 600.degree. C. in a nitrogen atmosphere, thereby **crystallizing the amorphous silicon** film to obtain a crystalline silicon film;

Therefore, an object of the present invention is to provide a method for fabricating a semiconductor device using crystalline silicon film which is small in surface irregularities and so smooth, free from pinholes and high in quality, and which is obtained by performing enough gettering of **metal** to obtain successful crystallinity and successful TFT characteristics.

In order to achieve the above object, the present invention provides a method for fabricating a semiconductor device comprising: a step for **crystallizing an amorphous silicon** film to obtain a crystalline silicon film by introducing a metallic element serving for acceleration of crystallization onto the amorphous silicon film, and by performing a first heating process in an non-oxidative atmosphere; a first gettering step for removing or reducing the metallic element present in at least a partial region of the crystalline silicon film by performing a second heating process in a non-oxidative atmosphere; a second gettering step for further removing or reducing the metallic element present in the region of the crystalline silicon film where the first gettering has been effected, by performing a third heating process in an oxidative atmosphere; and a step for removing oxide formed by the second gettering step.

The present invention also provides a method for fabricating a semiconductor device comprising: a step for **crystallizing an amorphous silicon** film to obtain a crystalline silicon film by introducing a metallic element serving for acceleration of crystallization onto a partial region of the amorphous silicon film, and by performing a first heating process in an non-oxidative atmosphere; a first gettering step for removing or reducing the metallic element present in

a region of the crystalline silicon film except regions of the crystalline silicon film vertically crystallized from the partial region, by performing a second heating process in a non-oxidative atmosphere; a second gettering step for further removing or reducing the metallic element present in the region of the crystalline silicon film where the first gettering has been effected, by performing a third heating process in an oxidative atmosphere; and a step for removing oxide formed by the second gettering step.

A **metal** serving for acceleration of crystallization remains in a state of compounds with silicon at grain boundaries in a crystalline silicon film. In the case that the **metal** serving for acceleration of crystallization is reduced by oxidation, oxidation considerably proceeds at grain boundaries where metals are present at high concentrations. Therefore, after the oxidation, irregularities of the crystalline silicon film surface are considerably increased, causing pinholes to be formed.

Therefore, in this embodiment, with respect to the **metal for crystallization** acceleration, a gettering process involving no oxidation (first gettering process) is first performed in non-oxidative atmosphere.

The **metal** concentration is reduced by the first gettering process to such a level that oxidation does not cause increase of irregularities or occurrence of pinholes. Then, a gettering process by oxidation (second gettering process) is performed, thus allowing enough **metal** gettering to be implemented.

A metallic element serving for acceleration of crystallization is introduced over the entire surface of an amorphous silicon film, and the amorphous silicon film is crystallized by a first heating process. Thereafter, oxide is deposited on the crystallized silicon film by CVD process and patterned, and phosphorus as an element which is easily combinable with the metallic element is implanted by ion implantation to the surface of the crystalline silicon film through the opening of the oxide pattern. Next, a second heating process is performed in a non-oxidative atmosphere containing inert gas such as nitrogen, hydrogen, **Ar, He,** etc., by which the metallic element is gettered into the

region of the **crystalline silicon** film where phosphorus has been implanted. One kind of element or a plurality of kinds of elements among nitrogen, arsenic, antimony and bismuth may also be implanted instead of phosphorus. Desirably, before a second gettering process which will be performed later, a region containing the region of the crystalline silicon film to which phosphorus has been implanted (i.e., a region where the metallic element has been gettered) is removed in advance, by which the metallic element is prevented from diffusing into the other regions and outward of the substrate from the region in later processes.

A metallic element serving for acceleration of crystallization is introduced over the entire surface of a amorphous silicon film, and the amorphous silicon film is crystallized by a first heating process. Thereafter, oxide is deposited on the crystallized silicon film by CVD process, and a second heating process is performed in a non-oxidative atmosphere containing inert gas such as nitrogen, hydrogen, **Ar, He,** etc., by which the metallic element is gettered into the oxide. In addition, a higher gettering effect can be obtained when the second heating process is performed in a non-oxidative atmosphere containing at least one kind of halogen element selected from among HCl, HF, HBr, Cl.sub.2, F.sub.2, Br.sub.2 and the like, which are easily combinable with the metallic element. Like this, whereas a patterning for implementation of phosphorus is involved in the first method, the patterning is unnecessary in this second method. Therefore, the second method can be fulfilled with simpler processes, and is capable of obtaining high yield with low cost, as compared with the first method.

A metallic element serving for acceleration of crystallization is introduced to amorphous silicon film at an opening portion with an oxide pattern used as a mask, and crystallized by a first heating process. Thereafter, further patterning is performed, and phosphorus is implanted into the surface of the crystalline silicon film, in which the oxide is opened, by ion implantation. Next, a second heating process is performed in a non-oxidative atmosphere containing inert gas such as nitrogen, hydrogen, **Ar, He,** etc., by which the metallic element is gettered into the region of the **crystalline silicon** film

where phosphorus has been implanted. One kind of element or a plurality of kinds of elements among nitrogen, arsenic, antimony and bismuth may also be implanted instead of phosphorus. Desirably, before a second gettering process which will be performed later, a region containing the region of the crystalline silicon film to which phosphorus has been implanted (i.e., a region where the metallic element has been gettered) is removed in advance, by which the metallic element is prevented from diffusing into the other regions and outward of the substrate from the region in later processes.

(2) As shown in FIG. 1B, by spin coating of an alcohol solution in which nickel acetate 23 has been dissolved to a concentration of 10 ppm, a **metal** of Ni serving for acceleration of crystallization is introduced to the surface of the amorphous silicon film 22. In this case, the Ni concentration at the surface of the amorphous silicon film 22 is 1.times.10.sup.13 atom/cm.sup.2. It is noted that as the method for introduction of the **metal** (Ni), sputtering process, CVD process, plasma processing and adsorption process may also be applied.

(3) A 12 hour first heating process is performed at a temperature of 600.degree. C. in a nitrogen atmosphere, thereby **crystallizing the amorphous silicon** film 22 as shown in FIG. 1C. As a result of analyzing the Ni concentration in a crystalline silicon film 24 by ICP-MS process, the Ni concentration was 1.5.times.10.sup.18 atom/cm.sup.2.

(16) After AlSi is deposited at a film thickness of 4000 .ANG. by sputtering process, interconnections (**metal** electrodes) 38 are formed in the contact holes 37 by using photolithography and dry etching.

(3) After removing the resist pattern, an alcohol solution in which nickel acetate 65 has been dissolved to a concentration of 10 ppm is applied by spin coating onto patterned oxide 64 and the amorphous silicon film 62 as shown in FIG. 4D, by which a **metal** of Ni serving for acceleration of crystallization is introduced to the surface of the amorphous silicon film 22 through the opening of the oxide 64.

a step for **crystallizing an amorphous silicon** film to obtain a crystalline silicon film by introducing a metallic element serving for acceleration of crystallization onto the amorphous silicon film, and by performing a first heating process in an non-oxidative atmosphere;

a step for **crystallizing an amorphous silicon** film to obtain a crystalline silicon film by introducing a metallic element serving for acceleration of crystallization onto a partial region of the amorphous silicon film, and by performing a first heating process in an non-oxidative atmosphere;

US-PAT-NO: 6013544

DOCUMENT-IDENTIFIER: US 6013544 A

TITLE: Method for fabricating a semiconductor device

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The present invention relates to a semiconductor device and a method for fabricating the same. In particular, the present invention relates to a semiconductor device using, as an active region, a crystalline silicon semiconductor film obtained by **crystallizing an amorphous silicon** semiconductor film formed on a substrate having an insulating surface, and to a method for fabricating the same. More specifically, the present invention is applicable to a semiconductor device using thin film transistors (TFTs) provided on an insulating substrate such as a glass substrate, an active matrix type liquid crystal display device, an image sensor, a three-dimensional IC and the like, and to the fabrication thereof.

The mechanism for the above-described low-temperature crystallization is as follows. First, crystal nuclei with **metal** elements as their nuclei are generated in the early stage of the heating process. After that, the **metal** elements act as catalysts to accelerate the crystallization, and the crystal growth proceeds rapidly. In this sense, such **metal** elements are hereinafter referred to as the catalyst elements.

While the crystalline silicon semiconductor films obtained by **crystallizing amorphous silicon** semiconductor films using ordinary solid-phase growth methods have a twin crystal structure, the crystalline silicon semiconductor film obtained by accelerating the crystallization using catalyst elements as

described above is formed from numerous column-like crystals. Moreover, an internal structure of each of the column-like crystals is in an ideal single crystalline state.

In the present invention, an important role is imposed on the setting of a temperature of the heat treatment (the second heat treatment) for **crystallizing** the upper amorphous silicon semiconductor film.

Specifically, in the case where the temperature of the second heat treatment is lower than a temperature required to crystallize the upper amorphous silicon semiconductor film, the catalyst elements are solely thermally diffused in the upper amorphous silicon semiconductor film. A concentration of the catalyst elements in the lower crystalline silicon semiconductor film is reduced to a certain degree owing to the thermal diffusion. In order to obtain satisfactory effects, however, it is desirable to set the temperature of the second heat treatment to a temperature equal to or higher than the temperature for **crystallizing** the upper amorphous silicon semiconductor film so as to certainly cause the crystallization thereof. When the temperature is set in such a manner, the catalyst elements effectively move in the upper amorphous silicon semiconductor film in accordance with the movement mechanism in the ternary system described above, so that the concentration of the catalyst elements remaining in the lower crystalline silicon semiconductor film serving as the active region (the device formation region) is greatly reduced.

In particular, setting the temperature of the second heat treatment to a temperature higher than that required to crystallize the upper amorphous silicon semiconductor film means that the temperature of the second heat treatment is set to a temperature higher than that required to crystallize the lower amorphous silicon semiconductor film (i.e., the temperature of the first heat treatment). According to such selection of the temperature, the catalyst elements, which remain and are trapped in the lower crystalline silicon semiconductor film, receive a thermal energy greater than that given when the catalyst elements were left in the lower crystalline silicon semiconductor film (in other words, a thermal energy applied during the first heat treatment for

crystallizing the lower amorphous silicon semiconductor film). As a result, it is possible to certainly cause the remaining catalyst elements to move into the upper amorphous silicon semiconductor film so as to surely and effectively remove the catalyst elements from the lower crystalline silicon semiconductor film serving as an active region (device formation region). Simultaneously, the grain boundaries of the lower crystalline silicon semiconductor film are effectively recrystallized to be well treated.

Furthermore, contact holes are formed through the interlayer insulating film 114 as shown in FIG. 2E. Electrodes/wirings 115 and 116 of the n-type TFT 100 are formed of **metal** materials, for example, of multi-layered films of titanium nitride and aluminum, and are connected to the source/drain regions 112 and 113. The titanium nitride film functions as a barrier layer for preventing aluminum from diffusing into the crystalline silicon layer 103i.

Next, contact holes are formed through the interlayer insulating film 217. Electrodes/wirings 218 through 220 of TFTs, which are formed of **metal** materials, for example, of multi-layered films of titanium nitride and aluminum, are formed and connected to the source/drain regions 213 through 216. As the final step, then, annealing is performed in a hydrogen atmosphere of 1 atm at about 350.degree. C. for about 30 minutes, thereby completing a CMOS structure having the n-type TFT and the p-type TFT.

In the thus formed n-type and p-type TFTs in Example 2, the base coat film 202 made of silicon oxide for preventing the diffusion of impurities from the substrate 201 is formed on the glass substrate 201, as can be seen in the cross-sectional view shown in FIG. 4F. In the crystalline silicon semiconductor film formed on the base coat film 202, the active region 203n of the n-type TFT including the source/drain regions 213 and 214 and the channel region 211, as well as the active region 203p of the p-type TFT including the source/drain regions 215 and 216 and the channel region 212, are formed. Furthermore, the gate insulating film 208 made of silicon oxide is formed thereon. On the gate insulating film 208, the gate electrodes 209 and 210 made of an aluminum film are formed so as to face the channel regions 211 and 212 of

the n-type TFT and the p-type TFT, respectively. The interlayer insulating film 217 made of silicon oxide is formed so as to cover the gate electrodes 209 and 210. The electrodes/wirings 218 through 220 consisting of a two-layered film of **metal** materials, for example, titanium nitride and aluminum are formed, which are electrically connected to the source/drain regions 213 to 216 via the contact holes formed through the gate insulating film 208 and the interlayer insulating film 217.

For example, in Examples 1 and 2 described above, in order to introduce the catalyst elements for crystallization into the lower amorphous silicon semiconductor film, a method for allowing the surface of the lower amorphous silicon semiconductor film to be in contact with the solution in which nickel salt is dissolved so as to apply the solution onto the surface of the film (Example 1) or a method for forming the nickel thin film by vapor deposition is employed. A minute amount of nickel is introduced into the lower amorphous silicon semiconductor film according to any one of these methods to cause crystal growth. Alternatively, the following method can be used instead. Before depositing the lower amorphous silicon semiconductor film, a minute amount of nickel is introduced into the base coat film. Nickel is then diffused from the base coat film into the lower amorphous silicon semiconductor film through the bottom face of the lower amorphous silicon semiconductor film, thereby **crystallizing** the lower amorphous silicon semiconductor film. In order words, the introduction of the catalyst elements into the lower amorphous silicon semiconductor film and the crystal growth resulting therefrom can be conducted either from the upper face or the bottom face of the lower amorphous silicon semiconductor film.

As a heating method for improving crystallinity of the crystallized silicon semiconductor film, the same effects can be accomplished by using other laser beams such as a continuously oscillating **Ar** laser. Furthermore, instead of using laser beams, other techniques such as rapid thermal annealing (RTA) or rapid thermal processing (RTP) can be employed. In the RTA or RTP process, a workpiece is heated to a high temperature of about 1000.degree. C. to about 1200.degree. C. (a silicon monitor temperature) in a very short period of time

using an infrared or flash lamp that provides an intense light equivalent in intensity to the laser beams.

	Type	Hits	Search Text	DBs	Time Stamp
1	IS&R	1	("6013929").PN.	USPAT; US-PGPUB	2003/05/15 14:07
2	IS&R	1	("5605847").PN.	USPAT; US-PGPUB	2003/05/15 14:16
3	BRS	65	(semiconductor adj energy adj laboratory) and (rare adj gas) and tft	USPAT; US-PGPUB	2003/05/15 14:24
4	BRS	10769	(He or Ne or Ar or Kr or Xe) same (silicon or polysilicon or polycrystalline or crystalline)	USPAT; US-PGPUB	2003/05/15 14:26
5	BRS	4698	(He or Ne or Ar or Kr or Xe) with (silicon or polysilicon or polycrystalline or crystalline)	USPAT; US-PGPUB	2003/05/15 14:27
6	BRS	649	((He or Ne or Ar or Kr or Xe) with (silicon or polysilicon or polycrystalline or crystalline)) and (crystallization or crystallizing)	USPAT; US-PGPUB	2003/05/15 14:27
7	BRS	518	(((He or Ne or Ar or Kr or Xe) with (silicon or polysilicon or polycrystalline or crystalline)) and (crystallization or crystallizing)) and metal	USPAT; US-PGPUB	2003/05/15 14:28
8	BRS	244	((((He or Ne or Ar or Kr or Xe) with (silicon or polysilicon or polycrystalline or crystalline)) and (crystallization or crystallizing)) and metal) and (amorphous adj silicon)	USPAT; US-PGPUB	2003/05/15 14:29
9	BRS	240	(((((He or Ne or Ar or Kr or Xe) with (silicon or polysilicon or polycrystalline or crystalline)) and (crystallization or crystallizing)) and metal) and (amorphous adj silicon)) and (annealing or heat or heating or irradiating or irradiation)	USPAT; US-PGPUB	2003/05/15 14:30

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9			0

	Type	Hits	Search Text	DBs	Time Stamp
10	BRS	224	(((((He or Ne or Ar or Kr or Xe) with (silicon or polysilicon or polycrystalline or crystalline)) and (crystallization or crystallizing)) and metal) and (amorphous adj silicon)) and (annealing or heat or heating or irradiating or irradiation)) not ((semiconductor adj energy adj laboratory) and (rare adj gas) and tft)	USPAT; US-PGPUB	2003/05/15 14:30

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